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RESEARCH ARTICLE

Leveraging Electronic Health Records to Develop Measurements for Processes of Care

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Objectives. To assess the reliability of data in electronic health records (EHRs) for measuring processes of care among primary care physicians (PCPs) and examine the relationship between these measures and clinical outcomes.

Data Sources/Study Setting. EHR data from 15,370 patients with diabetes, 49,561 with hypertension, in a group practice serving four Northern California counties.

Study Design/Methods. Exploratory factor analysis (EFA) and multilevel analyses of the relationships between processes of care variables and factor scales with control of hemoglobin A1c, blood pressure (BP), and low density lipoprotein (LDL) among patients with diabetes and BP among patients with hypertension.

Principal Findings. Volume of e-messages, number of days to the third-next-available appointment, and team communication emerged as reliable factors of PCP processes of care in EFA (Cronbach's alpha = 0.73, 0.62, and 0.91). Volume of e-messages was associated with higher odds of LDL control (≤100) (OR = 1.13, $p < .05$) among patients with diabetes. Frequent in-person visits were associated with better BP (OR = 1.02, $p < .01$) and LDL control (OR = 1.01, $p < .01$) among patients with diabetes, and better BP control (OR = 1.04, $p < .01$) among patients with hypertension.

Conclusions. The EHR offers process of care measures which can augment patient-reported measures of patient-centeredness. Two of them are significantly associated with clinical outcomes. Future research should examine their association with additional outcomes.

Key Words. Primary care, electronic health records, patient-centered care

Patient-Centered Medical Home (PCMH) is a promising model of care that aims to reinvent primary care, so that it is "accessible, continuous, comprehensive, and coordinated" (American Academy of Family Physicians et al. 2007; Blumenthal and Tavenner 2010) with an increased emphasis on team-based care (Peikes et al. 2012). Progress toward better quality, improved patient experience, and lower costs has been reported (Peikes et al. 2012). While it

has been recognized that at the center of integrated health care delivery is a high-performing primary care provider (PCP) who can serve as a medical home for patients (Meyers et al. 2010), the focus of current PCMH recognition measures is largely on practice-level characteristics (National Committee for Quality Assurance 2011a). If delivery systems broadly implement uniform changes, for example, installing electronic health records, implementing advanced access (Friedberg, Lai et al. 2009), however, such practice-level measures will have limited value in discerning the causes of heterogeneities in processes and outcomes of care across practices.

While implementing electronic health records (EHRs) at the organization level makes it less of a distinguishing feature about primary care transformation among its component clinics, the EHR can potentially offer measures of process of care that are consistent with some component standards for patient-centered medical homes (Friedberg, Lai et al. 2009). Therefore, the growing spread of EHRs provides valuable opportunities to health care organizations to routinely measure physician practice in an unobtrusive way. Indeed, some organizations already regularly take advantage of practice-based data (e.g., same-day access, e-message turn-around time) for operations purposes. There is strong interest in leveraging delivery organizations' capacities to use performance indicators to assess physicians and other professionals (Robinson et al. 2008; Mechanic 2010). Researchers can use these existing data to construct clinician-level measurements of patient-centeredness in clinical processes to potentially fill a gap in PCMH measurement tools.

We explored several EHR-generated PCP-level process of care measures following the key structural domains of the PCMH identified in the literature: enhanced access and continuity, informed care management, care coordination (Abrams, Schor, and Schoenbaum 2010; Rosenthal et al. 2010), and increasing opportunities for patients to participate in the care process (Bergeson and Dean 2006). These domains correspond to both the broad functional domains (e.g., care coordination capabilities) of the National Committee on Quality Assurance Physician Practice Connection-Patient

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Centered Medical Home (NCQA PPC-PCMH) assessment tool, and the core elements outlined in the Joint Principles of the Patient-Centered Medical Home (Rosenthal et al. 2010). We compared the process of care constructs in the literature with routinely collected EpicCare EHR data to examine: (1) if information in the EHR can be reliably used to operationalize constructs of process of care related to the aforementioned three domains of patient-centered care (Rosenthal et al. 2010) and (2) the relationship between these EHR-based measures and health outcomes among patients with chronic diseases. Because type II diabetes (DM) and hypertension are two of the most common chronic conditions, we chose to analyze clinical outcomes of patients with either of these conditions. Because blood pressure (BP), LDL, and A1C control are the most important management goals for patients with DM, we chose them as examples to test the clinical relevancy of the PCP-level patient-centeredness measures (Barr 2008; Peikes et al. 2012). We also analyzed BP control for patients with hypertension (Peikes et al. 2012; Rosenthal, Abrams, and Bitton 2012). Furthermore, we examined whether the level of NCQA recognition for patient-centered care, at the clinic level, was associated with clinical outcomes among patients with diabetes or hypertension for clinics within the group practice.

We hypothesized that some of the variables representing processes of care in the above-mentioned domains may be highly correlated and reflective of underlying latent characteristics of PCPs' propensity to practice patient-centered care. We further hypothesized that these highly correlated variables, if they indeed cluster with each other, would form factor scales that can be consistent with the domains of patient-centered processes of care practices. In addition, we hypothesized that these factor scales, if emerged, would be correlated with clinical outcomes. However, there may be stand-alone process of care variables at the PCP level—also available from the EHR or administrative data—that could be correlated with clinical outcomes. Lastly, we hypothesize that patients with diabetes or hypertension would be more likely to have better clinical outcomes if they were served by PCPs in clinics with higher levels of NCQA recognition for patient-centered care (described below).

METHODS

The Sample and Data Collection

The study took place in a large multispecialty medical group practice (the Group) during the period January 2010 to December 2010. The Group serves

over 650,000 patients in four counties in Northern California. Inclusion criteria were as follows: (1) active patient (at least one visit to a PCP at the Group in the 24-month period January 2009 to December 2010); (2) adult patient (18 years of age and older); (3) evidence of either type II diabetes mellitus and/or hypertension; (4) at least one BP, A1C, or LDL measurement in 2010 for patients with diabetes or at least one BP measurement in 2010 for patients with hypertension; and (5) had a PCP in internal medicine or family medicine department of the Group.

Evidence for diabetes and hypertension was defined by at least one diagnosis code from the problem list and/or two visit diagnoses on different days (ICD-9 codes used to identify diabetes were 250.X0 and 250.X2; and the ICD-9 codes used to identify hypertension were 401.x, 403.00, 403.01, 403.10, 403.11, 403.90, 403.91, 405.09, 405.11, 405.19, 405.91, and 405.99). All of the discrete elements of the EHR (for example, blood pressure data) are stored in an SQL database. To extract specific elements of the patient's medical record, we ran SQL queries programmed to extract data on blood pressure, lab results, etc. against the SQL database in the EHR for the study. Extracted data from the SQL database were then imported into Stata where they were used to construct PCP process of care measures over the 12-month study period. We obtained ambulatory care clinical access and quality measures data used routinely for quality of care monitoring by the Group (defined below).

Measures

Dependent Variables. To address the study goal of evaluating the overall effect of the process of care measures on clinical outcomes, we extracted the BP, LDL, and A1C measures for 2010 of all patients diagnosed with type II diabetes mellitus and the BP measures of all patients diagnosed with hypertension. When a patient had multiple BP or lab measurements in 2010, the average value was used to determine whether the measure was under control. Our dependent variables were as follows: BP under control (<130/80 mmHg for diabetics [Chobanian et al. 2003] and <140/90 mmHg for hypertensive patients), A1C $\leq$ 7.5 for diabetics, and LDL $\leq$ 100 for diabetics.

PCP Process of Care Measures. We used multiple variables to measure subsets of process of care measures that can be derived from the EHR with respect to the volume of electronic communication, team communication, and advanced

access. First, volume of electronic communication was determined from the number of electronic messages sent or received between patients and PCPs and the number of electronic messages sent or received between staff (excluding care managers) and PCPs. Second, team communication was measured by the number of staff messages between PCPs and care managers, who are mostly nurses with a small number of registered dieticians and a social worker, via the number of messages sent by a PCP to care managers and the number of messages received by a PCP from care managers. Although a formal analysis of the actual content of PCP-care manager messages was beyond the scope of this exploratory study, we did obtain some information on these communications from key informant interviews with care managers and clinicians (Dohan et al. 2013). For example, one care manager would inform the PCP that one of her patient with diabetes came to see the care manager who found that he had a serious foot infection and was accompanied by the care manger to the urgent care department. Third, advanced access (Murray and Berwick 2003) is measured by time to appointment, that is, the number of days to the third-next-available (TNA) short appointment (15 or 20 minutes per visit), and number of days to the TNA long appointment (30 or 40 minutes per visit).

A few additional stand-alone processes of care variables were also included for analyses. They are as follows: (1) Time with Own Patients (the annual percentage of visits the physician spends seeing his or her own patients); (2) See Your Own Patients (the percentage of the PCP's patients' total visits that are spent with themselves); (3) whether a physician practices in 15/30 minute short/long appointments (vs. 20/40 minute appointments); and (4) secure messaging response rate (the percentage of secure patient e-messages that the PCP answered within 1 day or the same day, excluding weekends). Lastly, we controlled for PCP's clinical FTE, specialty (family medicine vs. internal medicine), and workload (Patient Panel Size/FTE).

Covariates: Patient, PCP, Department, and Clinic Characteristics. Patient characteristics included gender, age, insurance (preferred provider organization [PPO] insurance plans, HMO, and other insurance), Charlson score (Charlson et al. 1987; Quan et al. 2005), number of visits in 2010, and self-reported race (non-Hispanic white, Asian, other race). Race data were obtained from patients using a questionnaire at office visits (Wong, Palaniappan, and Lauderdale 2010) and was missing for 9 percent of diabetes patients and 8 percent of patients with hypertension. Insurance data were missing for 0.3 percent of

diabetes patients and 0.4 percent of patients with hypertension. Due to the small number of observations in missing insurance data, we excluded those observations from the analysis file. Patients missing self-reported data on race were also excluded. Sensitivity analysis using imputed race data based on their last names following a previous published algorithm (Wong, Palaniappan, and Lauderdale 2010) yielded similar results.

PCP characteristics included gender and the number of years practicing in the Group. Department characteristics analyzed included department size in FTE and staff to physician FTE ratio (where staff includes medical assistants, nurses, patient services representatives, and physician assistants).

Lastly, we controlled for a clinic's status in NCQA's recognition for patient-centered care including Level III, Level II, versus did not apply (Dohan et al. 2013). Based on NCQA's assessment, a Level III clinic scores 75+ points of a total of 100 points, with ten of ten (10/10) "must have" components for patient-centered care; a Level II clinic scores between 50 and 74 points, 10/10 must haves; and a Level I: 25–49 points, 5/10 must haves. The detailed institutional background on why it decided to pursue NCQA recognition has been reported elsewhere (Dohan et al. 2013). Briefly, there was not a centralized effort to seek NCQA recognition at the level of the entire Group. The extensive reporting efforts required by NCQA were seen by some administrators as too demanding. Therefore, recognition was only sought for half of the primary care clinics, based on decisions made jointly between high-level administrators at the Group level and administrators at the clinic level (Dohan et al. 2013).

Data Analysis

To examine if information in the EHR can be used to operationalize constructs of volume of e-message, team communication, and advanced access, we computed Cronbach's Alpha to examine the internal reliability, followed by Exploratory Factor Analysis (EFA) to determine the number of latent factors. Factor scores were created for each emergent factor per PCP. The analysis was done in Stata.

We used three-level logistic random-intercept models to examine the relationship between the dependent variables and five vectors of explanatory variables: (1) PCP process of care factor scores (described in EFA analysis section) and stand-alone variables; (2) patient characteristics; (3) PCP characteristics; (4) department characteristics; and (5) clinic indicators including NCQA recognition level: III, II, or did not apply (Table 3). The unit of analysis was

the patient. The multilevel models accounted for the clustering of patients within PCPs, and PCPs within clinics.

RESULTS

Univariate Descriptive Statistics

Table 1 presents the univariate descriptive statistics for patient-level variables. The first column presents the results for patients with diabetes. About 50 percent of patients with diabetes had controlled BP (<130/80 mmHg); 79 percent had A1C ≤ 7.5; and 60 percent had LDL ≤ 100 in 2010. The average age was 62 years (SD = 15). About 47 percent of patients were female; 49 percent were non-Hispanic white; 30 percent were Asian; and 21 percent were other

Table 1: Characteristics of Patients with Diabetes and Patients with Hypertension

	Patients with Diabetes[†] *(n = 15,370)*		*Patients with Hypertension*[†] *(n = 49,561)*	
	%/Mean	*SD*	*%/Mean*	*SD*
Patient level				
BP under control[‡]	49.89%		72.73%	
A1C ≤ 7.5[§]	78.93%			
LDL ≤ 100[¶]	59.96%			
Female	46.83%		51.45%	
Age	61.90	14.93	62.97	14.77
Race				
Non-Hispanic White	48.95%		63.23%	
Asian	30.16%		21.69%	
Other	20.89%		15.08%	
Insurance				
PPO	63.60%		64.60%	
HMO	30.84%		31.04%	
Other	5.56%		4.36%	
Charlson score				
0			51.98%	
1	50.12%		21.97%	
2 or more	49.88%		26.05%	
Number of visits in 2010	7.29	6.97	6.51	6.19

[†]Includes diabetes patients who had BP, A1C, and/or LDL measurements.
[‡]Among patients with at least one BP measurement.
[§]Among patients with at least one A1C measurement.
[¶]Among patients with at least one LDL measurement.

race; 64 percent of patients had PPO; 31 percent had HMO; 6 percent had other insurance; 50 percent had a Charlson index score of 1, meaning that they had one serious comorbidity; and 50 percent had a Charlson index score of 2 or more, meaning that they had at least two serious comorbidities. The average number of in-person office visits (regardless of clinicians' specialty) in 2010 was 7 (SD = 7).

The second column of Table 1 presents descriptive information on patients with hypertension. About 73 percent of these patients had their BP under control in 2010. About 51 percent of them were female. Their average age was 63 years (SD = 15). With respect to race, 63 percent were non-Hispanic white. About 65 percent had PPO insurance, 31 percent had HMO, and 4 percent had other insurance. About 52 percent had a Charlson index score of 0, meaning that they did not have any serious comorbidities; 22 percent had a Charlson score of 1; and 26 percent had a Charlson score of 2 or more. (It is not surprising that more than half of the patients with hypertension scored 0 on Charlson index because hypertension is not a part of the index (Quan et al. 2005). The average number of total in-person visits (primary care and specialty care) in 2010 was 7 (SD = 6).

The descriptive statistics for the PCP, department, and clinic-level variables are presented in Table 2. Of 205 PCPs, 35 percent were male. The average length of practice in the Group was 10 years. The mean number of messages sent from PCP to staff was 467 (SD = 684) and the mean number of messages sent from PCP to patient was 258 (SD = 246). The mean time until the TNA short appointment was 3 days (SD = 3) and until the TNA long appointment was 7 days (SD = 7). Over the 12-month period, the mean number of messages sent to care managers by a PCP was 3 (SD = 6) and the mean number of messages sent by a care manager to PCP was 5 (SD = 7). Of the 13 clinics, four earned NCQA Level III recognition, five were recognized at Level II, and four did not apply for NCQA recognition.

EFA Analysis

Three factors emerged from EFA with Varimax rotation, explaining 79 percent of the total variance. We labeled Factor 1 "volume of e-message" because of high loadings on the number of messages sent or received between staff and PCPs and the number of messages sent or received between patient and PCPs. This factor explained 37 percent of the total variance (Cronbach's alpha = 0.73). Factor 2 was labeled "team communication" due to the high loadings by the number of messages sent or received between PCP and CMs.

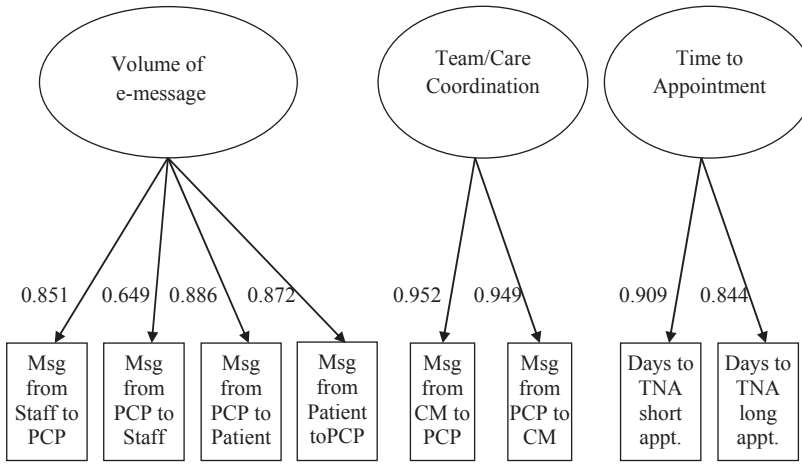
Table 2: Characteristics of Primary Care Physicians, Departments, and Clinics

	%/Mean	SD
Physician level (n = 205)		
PCP process of care variables		
No. of msgs from staff to PCP	366.53	325.99
No. of msgs from PCP to staff	467.07	684.46
No. of msgs from patient to PCP	360.71	326.50
No. of msgs from PCP to patient	258.05	246.41
No. of msgs from PCP to CM	3.23	5.61
No. of msgs from CM to PCP	4.86	6.54
Days to TNA short visit	2.66	3.22
Days to TNA long visit	7.26	7.43
15/30-minute appointments[†]	17.56%	
Continuity of care		
Time with own patients[‡]	80.99%	13.96%
See your own patients[§]	73.13%	6.71%
Secure messaging response rate[¶]	87.45%	8.98%
Male	34.63%	
Clinical FTE	80.23	16.32
Workload (panel size physician/FTE)	1,719.43	548.85
Years practicing at group	10.12	6.89
Specialty		
Family medicine	50.73%	
Internal medicine	49.27%	
Department level (n = 22)		
Department size	24.33	18.77
Staff to physician ratio	2.10	0.66
Clinic level (n = 13)		
NCQA Level III	4 of 13	
NCQA Level II	5 of 13	
Did not apply	4 of 13	

[†]Compared with PCPs usually providing 20/40-minute in-person visits.
[‡]Annual percentage of a physician's office visits that were spent seeing his or her own patients.
[§]Annual percentage of primary care office visits made by a physician's patients to their own physician.
[¶]Annual percentage of secure patient e-messages the PCP answered within 1 day, excluding weekends.

This factor explained 24 percent of the total variance with high reliability (Cronbach's alpha = 0.91). The third factor was labeled "time to appointment" due to high loadings by number of days to both the TNA short and long appointments. This factor explained 18 percent of the total variance with moderate reliability (Cronbach's alpha = 0.62). Figure 1 shows the path diagram illustrating the EFA model.

Figure 1: Exploratory Factor Analysis Model for EHR-Based PCP Process of Care Measures



Note: Msg= electronic message; TNA= third next available; CM= care manager; PCP= primary care physician; appt=appointment. The numbers on the arrows represent the rotated factor loadings.

In summary, we have identified three underlying constructs among the variables for PCP process of care factors that could potentially measure some aspects of their patient-centeredness. They measure volume of e-messages (electronic access to care), team communication, and time to appointment (physical access). The distinct loading patterns suggest that these three constructs are independent of one another.

Relationship between PCP Practice Pattern Factor Scores and BP, A1C, and LDL Control among Patients with Diabetes

The first three columns of Table 3 present the results of 3 three-level logistic random-intercept models for patients with diabetes (DM). Results from the model for BP control among patients with DM suggest that patients with more in-person office visits during the year (OR = 1.02, $p < .01$) and Asian patients (OR = 1.45, $p < .01$) had higher odds of having well-controlled BP. Older age (OR = 0.99, $p < .01$) and patients with other insurance (OR = 0.84, $p < .05$) and having a PCP with a higher workload (OR = 0.99, $p < .05$) was associated with lower odds of having good BP control. Besides PCP's workload, no PCP variables were significantly associated with BP control among patients with DM.

Table 3: Relationship between PCP Practice Pattern Factors and Clinical Outcomes: Results from Three-Level Logistic Random-Intercept Models

	Patients with Diabetes			*Patients with Hypertension*
	BP Control	*A1C ≤ 7.5*	*LDL ≤ 100*	*BP Control*
Physician level				
Factor score for volume of e-message	1.011	1.087	1.129*	0.984
Factor score for team communication	0.986	1.036	0.996	
Factor score for time to next appointment	0.985	0.988	0.987	0.977
15/30-minute appointments‡	1.104	1.142	1.034	1.121*
Time with own patients§	1.003	1.001	0.994	1.004
See your own patients¶	1.003	0.988	0.993	1.007
Secure messaging response rate‖	0.999	0.997	1.001	1.005
Male PCP	1.048	1.110	1.211**	1.019
Clinical FTE	0.997	1.000	0.995*	0.995
Workload of PCP	0.988*	0.983*	0.998	1.004
Years practicing at group	0.998	1.009	0.995	1.006*
Family medicine PCP	1.021	0.944	0.789**	0.993
Department level				
Department size	1.000	0.997	0.996	0.997*
Staff to physician ratio	1.008	1.021	1.043	1.067
Clinic level				
NCQA Level III	1.233	0.873	1.371*	1.288**
Did not apply	0.980	0.986	0.894	0.803*
Patient level				
Female patient	0.982	1.135*	0.648**	1.018
Patient age	0.994**	1.032**	1.023**	0.996**
Asian patient	1.450**	1.128*	1.119*	1.271**
Patient of other race	0.989	0.593**	0.925	0.912**
HMO insurance	0.984	0.914	0.975	1.001
Other insurance	0.837*	0.793*	1.032	0.881*
Charlson score of 1†				1.201**
Charlson score of 2 or more	1.025	0.687**	1.288**	1.209**
Number of visits in 2010	1.023**	0.995	1.009**	1.044**
Number of patients	15,101	12,121	11,462	49,561

**$p < .01$; *$p < .05$.

†All patients with diabetes have a Charlson score of at least 1, while patients with hypertension could have Charlson score of 0, 1, or 2. The default category for patients with diabetes is 1 and 0 is the default category for patients with hypertension.

‡Compared with PCPs usually providing 20/40-minute in-person visits.

§Annual percentage of a physician's office visits that were spent seeing his or her own patients.

¶Annual percentage of primary care office visits made by a physician's patients to their own physician.

‖Annual percentage of secure patient e-messages the PCP answered within 1 day, excluding weekends.

The second model examines the probability of having A1C under control ≤7.5). In terms of patient characteristics, female gender (OR = 1.14, $p < .05$), older age (OR = 1.03, $p < .01$), and Asian patient (OR = 1.13, $p < .05$) were associated with higher odds of having A1C under control and patients of other race (OR = 0.59, $p < .01$), other insurance (OR = 0.79, $p < .05$), and a Charlson score of 2 or more (OR = 0.69, $p < .01$) had lower odds of having their A1C under control. Patients who had a PCP with a higher workload (OR = 0.98, $p < .05$) were less likely to have their A1C under control. Similar to the findings on BP control, besides PCP's workload, no PCP variables were significantly associated with BP control among patients with DM.

Results from the model on the probability of having LDL ≤ 100 suggest that the factor for volume of e-messages was associated with higher odds of having LDL ≤ 100 (OR = 1.13, $p < .05$). In addition, patients with PCPs in Level III NCQA-recognized clinics had higher odds (OR = 1.37, $p < .05$) of having well-controlled LDL, compared with patients with PCPs practicing in Level II clinics. Furthermore, older patient age (OR = 1.02, $p < .01$), Asian race (OR = 1.12, $p < .05$), having a Charlson index score of 2 or more (OR = 1.29, $p < .01$), having more visits to the Group practice (OR = 1.01, $p < .01$), and having a male PCP (OR = 1.21, $p < .01$) were associated with higher odds of having LDL ≤ 100. In contrast, female gender (OR = 0.65, $p < .01$) and having a PCP with higher clinical FTE (OR = 0.995, $p < .05$) and who was in Family Medicine (OR = 0.79, $p < .01$) was associated with lower odds of having well-controlled LDL.

Relationship between PCP Practice Pattern Factor Scores and BP Control among Patients with Hypertension

The last column of Table 3 presents the results of a three-level logistic random-intercept model for BP control among patients with hypertension. With respect to PCP characteristics, having a PCP with more years of practicing in the group (OR = 1.01, $p < .05$) was associated with higher odds of having well-controlled BP. Compared with patients with PCPs practicing in level II clinics, patients whose PCPs practiced in Level III clinics (OR = 1.29, $p < .01$) had higher odds of having BP under control. In contrast, those in clinics that did not apply for NCQA recognition had lower odds (OR = 0.80, $p < .05$) of BP control. Interestingly, patients served by PCPs who routinely used 15/30-minute visit lengths as opposed to 20/40-minute visit lengths had higher odds of having BP under control (OR = 1.12, $p < .05$). None of the

other PCP process of care variables or factors was significantly associated with BP control among these patients.

With respect to patient characteristics, Asian patients (OR = 1.27, $p < .01$) and patients with more visits (OR = 1.04, $p < .01$) were more likely to have well-controlled BP, while other race (OR = 0.91, $p < .01$), other insurance (OR = 0.88, $p < .05$), and older age (OR = 1.0, $p < .01$) were associated with lower odds of having well-controlled BP. Patients with Charlson scores of 1 (OR = 1.20, $p < .01$) and scores of 2 or more (OR = 1.21, $p < .01$) had higher odds of having good BP control, compared with patients with a Charlson score of 0.

DISCUSSION

Leaders in the PCMH movement have emphasized the need for reliable measures of patient-centeredness (Robinson et al. 2008; Nutting et al. 2009; Stange et al. 2010). Using EHR data, we used EFA and identified three reliable, independent constructs of PCP process of care to measure a subset of domains of patient-centeredness. All of these practice-level elements—volume of e-messages, time to appointment, and team communication—were incorporated in the NCQA's 2011 standards for patient-centered medical homes (National Committee for Quality Assurance 2011b). Although each of them had good-to-excellent reliability as factor scales, only one of these factors was significantly associated with a clinical outcome measure. That is, LDL control among patients with diabetes was better for patients whose PCP had high volumes of e-messages. Frequency of visits with physicians was associated with better cholesterol and blood pressure control among patients with diabetes and with better blood pressure control among patients with hypertension. These results are consistent to previous literature that documented the positive relationship between the time to reaching the diabetes treatment goals and the frequency of clinical visits by patients with diabetes and their physicians (Morrison, Shubina, and Turchin 2011).

The results of the study need to be viewed in the context of some limitations. First, our approach only partially captured the core attributes of primary care (Starfield 1998) and PCMH (Friedberg, Lai et al. 2009). The EHR lacks some measures of patient-centeredness, for example, more detailed information on patient–physician communication and shared decision making, and patient-reported outcomes and experience. Second, we did not carry out a formal qualitative analysis of the content of staff messages between the PCPs and

care managers, due to resource constraints. Third, the outcomes examined in this study are a small subset of the quality measures for PCMH within other chronic conditions, in acute care, and preventive care (Rosenthal, Abrams, and Bitton 2012). Fourth, the study was conducted in one large group practice in Northern California. The generalizability of findings is limited as a result. Further research involving more practices is required to refine this approach. Fifth, routine practice data in the EHR are collected for clinical and billing uses, not research. For example, the lack of patient-reported information on self-management of chronic conditions subjects the study to omitted variables bias. Moreover, we were unable to accurately determine how many patients had actual encounters with a care manager as those encounters tend not be billable. Furthermore, only some PCPs refer to care mangers those patients with diabetes who are not adhering to treatments or who are not responding to treatments in satisfactory ways. Of the 15,370 diabetes patients analyzed in this study, only 145 (0.9 percent) were referred to in a staff message between a care manager and a PCP in 2010. This might be the lower bound of the proportion of patients who are comanaged by PCPs and care managers; however, as some care managers and PCPs would discuss individual patients over the phone or in person instead of using staff messages. Rather than eliminating this factor scale from the analysis, we kept it in because its inclusion was guided by conceptual thinking. With more organizations embracing team care and care coordination, this conceptually sound and internally reliable factor could become significantly associated with clinical outcomes in real-world practice.

In addition, by including only active patients as defined by the Group, we excluded those who did not come actively to care, but who can still represent an important part of a PCP's population. Our data suggest that active patients represented about 81 percent of all patients assigned to their PCPs. On average, those "non-active" patients were older (65 vs. 62, $p < .01$), more likely to be male (57 percent, $p < .01$), and healthier (54 percent had a Charlson score of 1, $p < .01$). Due to the limitation of EHR that only records clinical data associated with clinical encounters, we were unable to include nonactive patients because the EHR would not have measurements on their blood pressure and laboratory results.

In conclusion, this study contributes innovative process of care measures that are easily derived from the EHR and can partially reflect PCPs' patient-centeredness. Some of them are significantly associated with clinical outcomes of two prevalent chronic conditions. Future efforts should examine the relationship between these measures and a broader set of quality measures

for PCMH. As more delivery organizations implement EHR (Blumenthal and Tavenner 2010), the EHR can be leveraged to obtain process of care measures that are consistent with some component standards for patient-centered medical homes (Friedberg, Coltin et al. 2009; Rosenthal et al. 2010). The quantity and real-world nature of EHR data provide added value for quality improvement and monitoring that can be done with relative low cost. With careful assessment for completeness and proper statistical transformation, the opportunities for using operations data for research on patient-centered process of care measures are remarkable. Delivery organizations and insurers should examine these measures to assist with quality improvement efforts. Continued efforts are needed to improve the quality of EHR data, through attention to standards that will lead to improved data capture and its use for analysis and promotion of patient-centered care.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.